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NOTE ON THE RADIATION FROM STARS.

By W. W. COBLENTZ.

The termination of the present investigation marks a new epoch in radiometry, especially as applied to the measurement of weak radiations. It makes available to the astronomer one more instrument for the investigation of celestial objects. This, of course is not the first attempt to measure the radiation ("heat") from stars. The previous ones were the stepping-stones which gave positive indications of heat from stars.

We "see" the stars with our eyes, and it goes without saying that when we can produce instruments which are proportionately sensitive to the eye, we shall be able to measure the "light," the radiations, emitted by stars.

The present instrument (a thermo-element) is perhaps a hundred times as sensitive as some of the radiometers used in previous attempts at the measurement of stellar radiation. With it quantitative measurements were made on stars down to the fifth magnitude and highly qualitative measurements were made on stars down to the seventh magnitude.

At various times during the past three or more years stellar thermopiles were constructed. In the early attempts several thermojunctions were placed in a small space—about 1^{mm} in diameter. As I became more familiar with the astronomical side of the problem and realized that a star image at best is a mere point of light, the mode of construction was entirely reversed. The utmost simplicity of construction was undertaken. Instead of several thermojunctions (a "thermopile") a single thermoelement is now employed. The materials used (bismuth and platinum; or bismuth and an alloy of bismuth and 3 per cent tin) are of the smallest workable dimensions to reduce the heat capacity. In fact, the sensitivity attainable depends more upon low heat capacity and low heat conductivity than upon the thermo-electric power of the material used.

The receivers attached to the thermojunctions were 0.3^{mm} to 0.4^{mm} in diameter. From two to three of these thermoelements were mounted in a glass receptacle (shown in Figure 1, *E*) and the best element was used in making the measurements. The air was exhausted through the stop-cock, *S*. The last traces of air were absorbed by heating metallic calcium, *Ca*, contained in a quartz-glass tube. The vacuum was tested by joining the terminals, *P*, to an induction coil. The rays from a star, after reflection from the mirror pass through the fluorite window, *F*, and are brought to focus on the receiver, *E*. The rear side of the receptacle is covered with a thick piece of plate glass, *G*, thru which is made the adjustment of the star image upon the thermoelement. The whole is mounted in a metal box (*B*, Figure 2), which is attached to the photographic plate holder of the reflector by means of the two screws, *S*. An absorption cell of water, 1^{cm} in thickness, is contained in the hinged metal box, *A*. The metal box, *L*, containing the right-angled prism and a lens for viewing the star-image from the side of the telescope tube, are the regular attachments to the Crossley reflector. The whole is mounted in the central axis of the reflector, with the glass tube pointing downward toward the large reflecting mirror. These attachments were constructed in Washington, D. C., and carried to Mt. Hamilton, Cal., a distance of over 3,100 miles without serious mishap. A vacuum pump was shipped, but it was not unpacked. The equipment consisted of two glass holders as shown in Figure 1. The slight vapors given off from the cement and stop-cock grease were removed by occasionally heating the calcium by means of a small alcohol blast lamp.

The electric current generated by the thermoelement, when a star image was focused upon one of the receivers, was measured by means of an iron-clad Thomson galvanometer, shown in Figure 3. In the galvanometer the coils are imbedded in blocks of Swedish iron. One of the outer iron shields (of

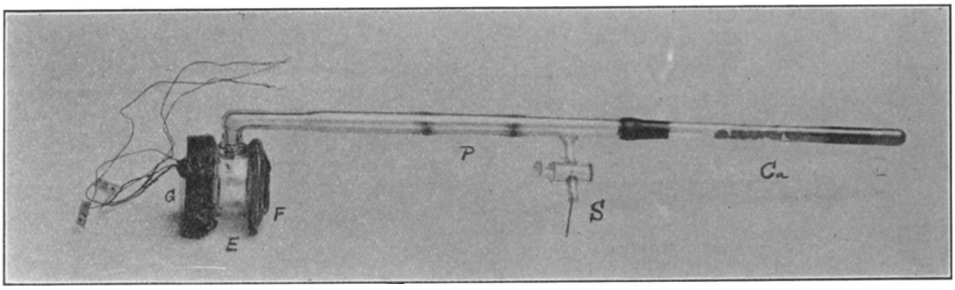

FIGURE I.

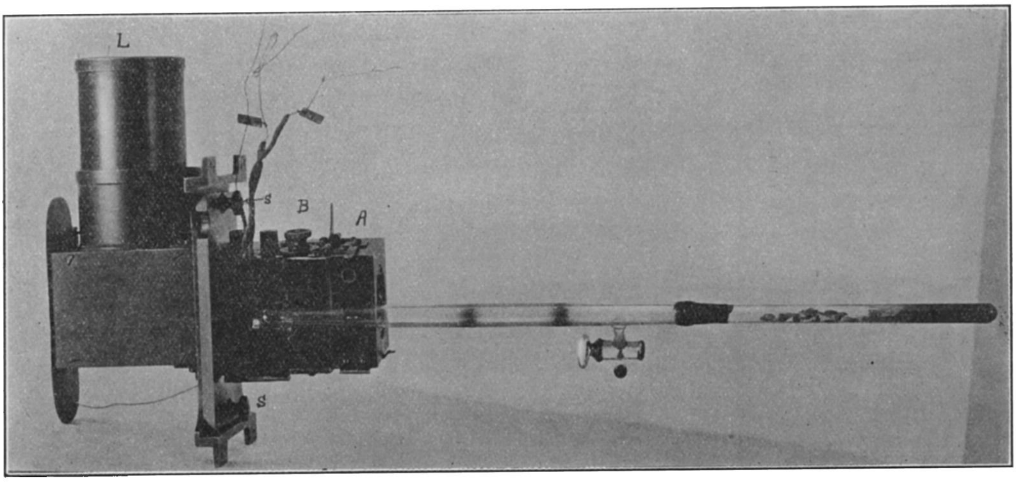

FIGURE 2.

transformer iron) is shown in Figure 3. The galvanometer stood upon the south pier, which supports the reflector. Only when the telescope was pointed low to the northern sky, which brought the lower end of the telescope tube close to (within one meter of) the galvanometer, did the rotation of the telescope affect the galvanometer. A galvanometer reading could be obtained in three to four seconds.

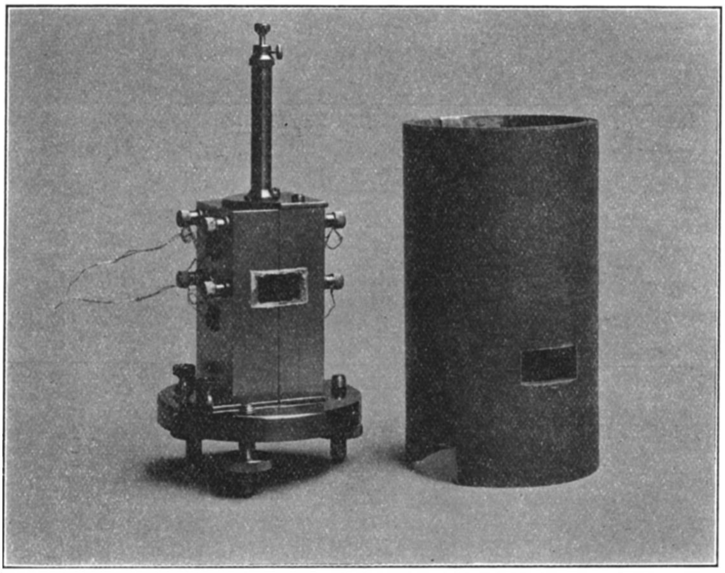

FIGURE 3.

The mirror of the Crossley reflector is 534^{cm} in focal length and it has an aperture of 92^{cm}. The support for the plate holder is 22^{cm} in diameter. In other words, the central position of the mirror, 22^{cm} in diameter, is shadowed by the plate-holder.

The thermoelement differs from the selenium and photoelectric cells, first, in that it is non-selective to the rays of different frequencies falling upon it, i. e. it absorbs all the radiations of all frequencies falling upon it, and, second, in that the response to the stimulus (the heating effect) is proportional to the energy falling upon it. It is an instrument adapted to quantitative measurements of radiant energy. It is far less sensitive than the selenium cell. The latter is, of course, not adapted to solving some of the problems discussed on a subsequent page.

From this brief description, it is evident that one of the principal achievements is in demonstrating that with an equipment of several thermoelements mounted in evacuated receptacles, one can go to the remotest station for radiation measurements without taking a cumbersome vacuum pump.

The whole work being merely a preliminary survey to determine what is possible by way of observing spectral energy curves of stars, no special pier was provided for the galvanometer, and no attempt was made to attain a high galvanometer sensitivity. In fact, the current sensitivity, which was of the order of $i = 2 \times 10^{-10}$ ampere, did not exceed that usually employed at the Bureau of Standards.

RESULTS OF THE RADIATION MEASUREMENTS.

The data obtained on stellar radiation, by means of these instruments, are too extensive to permit a detailed description in this brief note. The radiation from over one hundred celestial objects has been measured. No measurements were attempted on stars of less than the seventh magnitude, owing to the difficulty (lack of illumination) in projecting the star-image centrally upon the receiver. Furthermore, it was not apparent that much would be achieved in this preliminary work by so doing. The humidity during the summer nights on Mt. Hamilton falls below 10 per cent and any slight variations in humidity have a marked effect upon the radiometric measurements, especially upon red stars, which have the property of emitting a great amount of infra-red radiation.

As standards of radiation for intercomparing the observations, made on different nights, *Arcturus, Vega, Altair, γ Draconis,* and other stars were used.

After observing for several nights, it was found that the red stars emitted far more radiation than the blue ones having the same visual magnitude, and attention was given mainly to the solution of this question. Accordingly stars were selected having the same magnitude, but differing in color; and which were close together to eliminate the effect of air mass.

As the work progressed, it became a rather instinctive feeling to avoid the blue stars of less than the fourth magnitude, owing to the difficulty of measuring their radiation. But if this had been merely an attempt to show the possibilities of the instruments, then by selecting red stars, and by increasing the galvanometer sensitivity, positive indications could have been obtained of radiation from stars of the eighth to ninth magnitude. That, however, would simply be a spectacular achievement, and under the present conditions of observation, could not contribute much to science.

The detailed data, which have been accumulated, will be published elsewhere as soon as possible. A general survey of the data at hand indicates, first, that the individual stars of any given spectral class (say Class F), having the same photometric brightness, differ in the amount of energy emitted. This is, of course, to be expected, for no two stars can be expected to have exactly the same emissivity. Furthermore, their size, density and chemical constitution are no doubt vastly different. Second, the stars of different spectral classes (e. g. Class B as compared with Class M) differ greatly in emissivity. The blue stars (Class B, A) radiate much less energy (perhaps 50 per cent less) than the solar stars (Class F, G), and the latter, in turn, emit a less amount of energy than the red stars (Class M). The stars of Class M in general no doubt emit less energy than do the stars of Class N. The star ϕ *Pegasi,* Mag. = 5.23, Class Ma, gave a deflection of 2.8^{mm}, while the much redder star, 19 *Piscium,* Mag. = 5.30, Class N, gave a deflection of 5.7^{mm}. Only one star of Class N was conveniently placed for observation; but from the observations on numerous stars of Class M as compared with blue and yellow stars of the same magnitude, it is to be expected that stars of Class N will be found to have, as a general rule, the highest emissivity of all. Among all the data thus far accumulated, there are no exceptions to this general classification.

In Class M two stars (β *Pegasi* and α *Herculis*) are conspicuous for what may be termed an excessive total radiation, as compared with their photometric brightness. Instead of causing a galvanometer deflection of only a few millimeters they produced a deflection of two to three centimeters.

Of the double stars, measured radiometrically, the star γ *Andromedæ* is an excellent example. The star A (Mag. = 2.28) belongs to the Class K, and the component, BC (Mag. = 5.1) is blue. The intensity of the radiation from the latter is perhaps only about one half that observed from the red star H. R. 7676 *Draconis* (Class Ma), which has a photometric magnitude of 5.4.

To some, of course, the information gained radiometrically is not unexpected. The pioneering work of NICHOLS, some 14 years ago, showed that *Vega* and *Arcturus,* which have closely the same visual magnitude, differ greatly in their total radiation. He found the ratio of their emission (*Arcturus* to *Vega*) to be 2.2. My own observations, for different atmospheric conditions, give a value of 2.42 for the relative intensities of the radiation from *Arcturus* and *Vega.* Of course no conclusions could be drawn from observations on a single pair of stars, and the present generalization, which is based upon the measurement of over five score celestial objects, may also eventually require modification. Thus far, however, no exceptions have been found under the conditions imposed, viz., first, stars close together to eliminate the question of air mass; second, stars of the same visual brightness but differing in color. It was found that the red stars suffer the greatest absorption by water vapor, as was to be expected; but since they are observed to emit the most radiation the conclusions drawn are not invalidated.

The total radiation received from a star is a function of its size, distance, temperature, and especially of its emissivity. The latter is a function of the kind and the physical condition of the material which forms the radiating layer of the stellar surface. To eliminate the effect of the size and the distance of a star upon the quality of the radiations received, measurements were made in which the stellar rays were passed thru a layer of water 1^{cm} in thickness. The water absorbs all the infrared rays of wave-lengths greater than $1.4\ \mu$, and gives a rough comparison of the distribution of energy in the spectrum. The ratio of the galvanometer deflection caused by the stellar rays falling upon the thermoelement after passing thru the water (i. e. those rays which are transmitted by the cell of water) to the deflection caused by all the stellar rays collected by the mirror and concentrated upon the thermoelement, gives the "*transmission.*" If the total radiation from a red star contains more infra-red rays than does the total radiation from a blue star, then the amount transmitted by the water cell will be less for the red than for the blue star. This is the true condition of affairs, as may be noticed in Table I, which gives the percentage of the total energy falling upon the thermopile, which is transmitted by the water-cell, for red, yellow, and blue stars.

TABLE I.

	Transmission thru water-cell.
Class B, A—	
α *Lyræ,* A	58%
α *Aquila,* A_5	69
Class F, G, K—	
α *Auriga,* G	48
α *Bootis,* K	45
α *Tauri,* K_5	35
γ *Draconis,* K_5	32
Class M—	
β *Pegasi,* Mb	29
α *Scorpii,* Map	27
α *Herculis,* Mb	21

From this table it may be seen that as much as 60 per cent of all the radiations coming from a blue star, lies in the spectral region to which the eye is sensitive, while only from 20 to 30 per cent of the total radiation received from a red star affects the eye and the photographic plate. This brings out very clearly why it is that a red star of the same visual magnitude as a blue star (causes a larger galvanometer deflection) emits from two to three times as much total radiation. It means that from 70 to 80 per cent of the radiation from a red star lies in the infra-red—beyond the spectral region to which the eye is sensitive.

The absorption cell tells us nothing of the size and the distance of the star. It simply indicates that the shape of the stellar spectral energy curve is such that only about one-fourth of the total energy emitted from a red star lies in the visible and in the ultra-violet part of the spectrum. However, it should dispel all doubt as to the quality of the radiations emitted by red and by blue stars.

As a rough comparison, it may be stated that blue stars emit two times as much "light" as the yellow stars and three times as much "light" as the red stars. This no doubt is owing to a difference in the emissivity of the radiating layer of these different types of stars. The blue star may be at a higher temperature than the red star, but the total radiation emitted by the former may be less than from the latter, as observed in this investigation. It means that the rate of cooling of a blue star, as a result of loss of heat by radiation, is less than the rate of cooling of a red star.

Measurements were made on the "light" reflected from the bright and the dark bands of *Jupiter*. Both gave practically the same transmission thru the water cell, showing that whatever may be the cause of the dark bands, the diminution in brightness is quite non-selective as regards the infra-red. Interesting measurements were made on *Saturn* and its rings. Measurements on a planetary nebula showed no positive indications of radiations from it. However, from the observations on blue and red stars, it was not expected that definite indications of ("heat") radiations from nebulæ would be obtained.

From 50 to 60 per cent of the light reflected from *Venus, Saturn,* and *Jupiter* is transmitted by the water-cell. On the other hand, only 14 to 15 per cent of the light of the Moon was transmitted by the water-cell. The explanation given is that the lunar surface becomes quite warm from exposure to the Sun and in turn radiates heat waves, which are not transmitted by the absorption cell. The albedo of the Moon being much less than that of the planets, it should become heated to a higher temperature and the transmission thru the absorption cell should be the least, as observed.

In conclusion I cannot express sufficiently the feeling of gratitude for the opportunity which enabled me to make these measurements. In a half-hearted way, at odd times during the past few years, I have constructed thermojunctions for stellar radiation measurements, but obstacles (some not entirely impersonal) would come in the way of testing them. I am therefore very grateful to my colleague, Dr. K. BURNS, whose enthusiasm kept me at the later stages in the work of construction and testing of stellar radiometers, in view of the importance of astronomy. To Mr. S. B. NICHOLSON, who operated the reflector on several nights, and to Mr. W. K. GREEN, who performed this duty during the remainder of the work, I am greatly indebted for the assistance rendered. To Dr. W. W. CAMPBELL, Director of Lick Observatory, who placed the Crossley reflector and the assistants at my disposal, and to Dr. S. W. STRATTON, Director of the Bureau of Standards, who detailed me officially to carry on the investigation, I am especially indebted for the courtesies extended.

What is needed for extending the work is evident, viz., a large reflector seven to nine feet in diameter, situated in a superb location like Mt. Hamilton as regards climatic conditions, and set apart primarily for work in stellar radiation. When one thinks of all the money wasted in idle pleasure and in the wars of nations, it seems rather ironical to discuss this matter. However, I shall retrace my steps over the 3,100 miles to renew my efforts to further increase the sensitivity of the radiation instrument, hoping that thru some opportunity, equally as unforseen as was this one, I may be enabled to continue the work.

MT. HAMILTON, CAL., August 28, 1914.